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The biomechanical comparison of screw fixation and cross pinning methods in salter harris type 2 distal femoral fractures using the finite element method

Fixation biomechanics in pediatric distal femoral fractures

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Abstract
Aim: The most common type of distal femur physis fractures is Salter-Harris type 2 (SH type 2). These fractures have high complication rates and can cause a significant loss of function. Anatomical reduction is important in treatment. In this study, we aimed to compare two methods commonly used in SH type 2 fractures, cross pinning, and two parallel screw fixation methods using the finite element method.
Material and Methods: The SH type 2 fracture model was created in the femur model obtained from the 3-dimension (3D) computed tomography (CT) scans. The fracture in the first model was fixed with crossed Kirschner (K) wires. The fracture in the second model was fixed with two parallel screws placed from the metaphyseal part. The two models created were moved to the Ansys Workbench program. Axial overload, varus, valgus, anterior, posterior bending, and torsional forces were applied and analyzed with the 3D finite element method.
Results: In axial overload, the max stress in growth cartilage K wire was 0.40 MPa, while in the screw- 1.24 MPa. The varus bending was 0.32 MPa and 1.71 MPa, respectively. Also, the valgus bending was 0.15 MPa and 0.56 MPa, respectively. The anterior bending was 0.85 MPa and 1.30 MPa, respectively. Also, the posterior bending was 0.56 MPa and 2.01 MPa, respectively When torsional force was applied, it was found as 0.008 MPa and 0.16 MPa, respectively.
Discussion: In SH type 2 distal femoral fractures, the cross-pinning method is superior to the two parallel screw methods placed from the metaphyseal part in bending, torsion and axial loads.

Keywords
Finite element; Cross pinning; Screw fixation; Physis fracture

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Introduction

Distal femoral physeal fractures compose less than 1% of pediatric fractures. It constitutes 6-9% of the physis fractures [1,2]. Distal femur epiphysis provides 70% of the lengthening of the entire femur and 40% of the lower limb lengthening [3]. Various complications due to physeal injury, such as deformity formation and extremity length discrepancy, can cause morbidity. [4].

The Salter-Harris classification is used for the classification of these fractures [5]. This classification is important when choosing treatment and determining prognosis. According to the Salter-Harris fracture classification, four types of fracture are defined. The most common one of these is the Salter-Harris type 2 fracture (SH Type 2) [6,7]. Conservative and surgical treatment methods can be preferred in the treatment of these fractures according to the displacement amount of the fracture [8]. In type 2 distal femoral epiphysis fractures, it is important not to damage the growth cartilage as much as possible and to provide a stable fixation in treatment. Cross-pinning and fixation with two parallel screws placed from the metaphyseal part are commonly the preferred fixation methods [9]. Although there are various studies on the clinical results of these methods, there are not enough studies comparing these two methods biomechanically. In this study, we biomechanically compared the cross-pinning methods with two parallel screws placed from the metaphyseal part for fracture, which has sufficient metaphyseal parts, using the finite element method.

Material and Methods

The Finite Element Method (FEM) is a mathematical based computational technique used in solving complicated and analytically difficult structural problems. In this way, one creates a model similar to real body with solid modeling programs such as SolidWorks. This model was obtained using real CT images from real CT scans. The modified solid model in the solid modeling program according to the problem is then sent to analysis software such as Ansys Workbench. Ansys Workbench is a useful tool for especially engineers to solve various engineering problems by modeling them.

The femur model we used in our study was obtained from a three-dimension (3D) computerized tomography (CT) scan. The SH type 2 fracture model was created in the femur model. The fracture in the first model was fixed with crossed2.5 mm Kirschner (K) wires. The fracture in the second model was fixed with 4.5 mm fully threaded two parallel screws placed in the metaphyseal part (Figure 1).

The two models created were transferred to the Ansys Workbench program and analyzed using the 3D finite element method by applying axial loading, varus bending, valgus bending, anterior bending, posterior bending, and torsional forces. Von Mises stress distributions in growth cartilage were recorded as megapascal (MPa).

Higher-order Solid187 3D elements were used to generate a fine Finite Element mesh volume. The contact interfaces with the bone to screw and K-wires were assumed bonded contact. The fracture interface was considered completely broken, the frictional sliding contact and the friction coefficient was taken as 0.2 [10]. Bone to growth cartilage interface was considered as friction and 0.04 as a friction coefficient. Considering and analyzing six different load configurations for each model, simulating real-life physiological loads: Axial Loading with 350N from femur head by fixing the epiphyseal plate,150 N. moments from the epiphyseal plate by fixing the metaphysis and diaphysis, and 150N transverse force from the epiphyseal plate by fixing the metaphysis and diaphysis in the varus, valgus, anterior and posterior directions [10] (Figure 2).

Material properties were used for simulations as cortical bone E= 16GPa, u=0.3, growth cartilage E= 5MPa, u=0.46 and E=110GPa, u=0.33 as screw and K-wires and assumed linear elastic and isotropic [10].

Results

When the von Misses stress distribution in the growth cartilage was examined, the maximum stress was 0.40 MPa in the model fixed with K-wire in axial loading, while the maximum stress was found as 1.24 MPa in the model fixed with a screw (Figure 3 a1, b1). In varus bending loading, K-wire and screw models were found to be 0.32 MPa and 1.71 MPa, respectively (Figure 3 a2, b2). Valgus bending loading was 0.15 MPa and 0.56 MPa, respectively (Figure 3 a3, b3). While the anterior bending loading was 0.85 MPa and 1.30 MPa, respectively, the posterior bending loading was 0.56 MPa and 2.01 MPa (Figure 3 a4, b4, a5, b5). When the torsional loading was applied, the maximum stress in the growth cartilage was 0.008 MPa in the model applied to K-wire and 0.16 MPa in the screw applied model (Figure 3 a6,b6) (Table 1)

Table 1. Representation of stress values in growth cartilage

Loading type	Fixation type	Fixation type
	K.wire	Screw
Axial	0.40 MPa	1.24 MPa
Varus	0.32 MPa	1.71 MPa
Valgus	0.15 MPa	0.56 MPa
Anterior	0.85 MPa	1.30 MPa
Posterior	0.56 MPa	2.01 MPa
Torsion	0.008 MPa	0.16 MPa

MPa: Megapascal

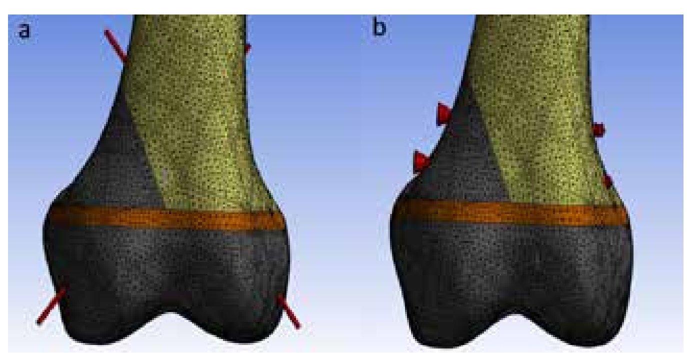

Figure 1. Salter-Harris type 2 fracture modeling. a) fixation with cross-pinning technique b) fixation with two screws parallel to the metaphyseal part.

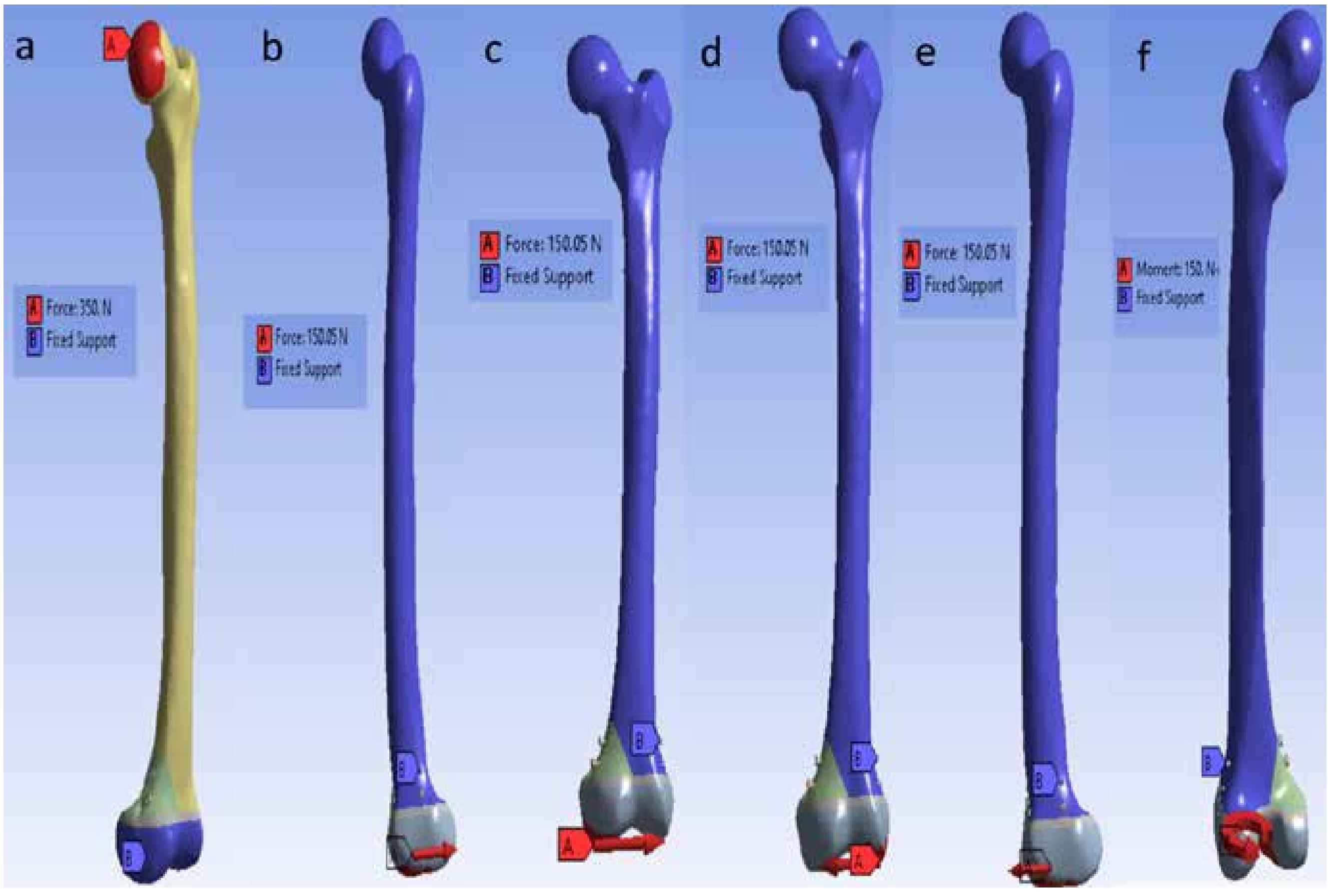

Figure 2. The presentation of loading forces a) axial loading b) anterior bending c) valgus bending d) varus bending e) posterior bending f) torsion

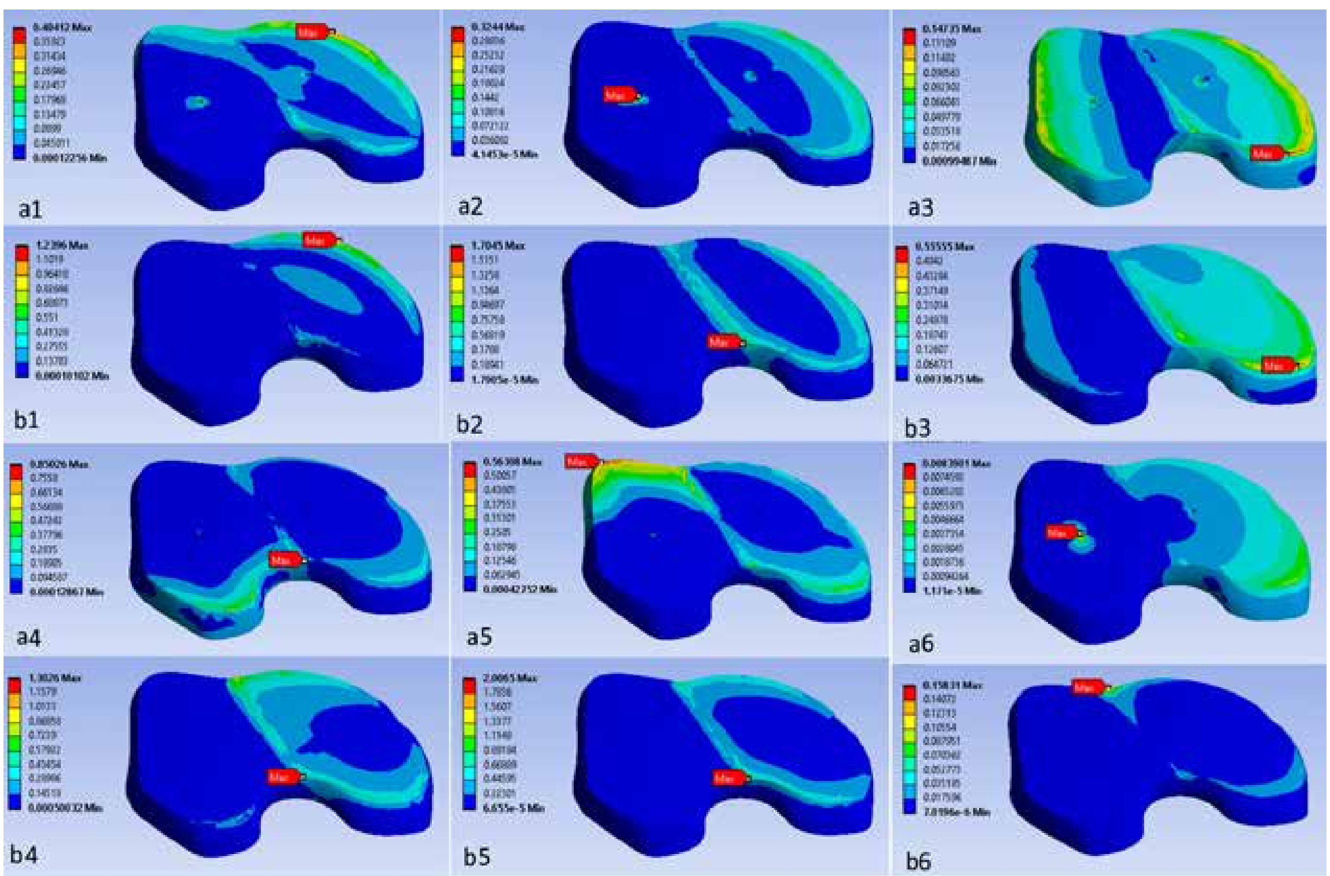

Figure 3. The presentation of von Mises stress distributions in growth cartilage under axial (a1,b1), varus (a2,b2), valgus (a3,b3), anterior bending (a4,b4), posterior bending (a5,b5) and torsion (a6,b6) loadings. a1, a2, a3, a4, a5, a6 : Fixation with K-wire. b1, b2, b3, b4, b5, b6 : Fixation with two parallel screws.

Discussion

The result of this study is that fixation with parallel two screws from the metaphyseal part for SH type 2 fractures under physiological loads causes higher stresses in the growth cartilage than fixation with cross-K wire.

Salter and Harris stated that type 1 and type 2 epiphyseal fractures are relatively benign and have a good prognosis according to their classification [5]. However, in many studies, unsuccessful results have been reported with a high incidence of Salter Harris type 2 fractures [11]. Abulfotooh et al. found 53.8% of satisfactory results in their study [3]. They concluded that these fractures should not be regarded as innocent fractures with a good prognosis. They stated that there was a reduction loss of up to 30% after closed reduction and plastering, displacement over 2 mm was critical, and anatomical reduction and internal fixation increased success [3,12]. Arkader et al. found 33% bad results in their studies [13]. Since SH type 2 fractures do not directly concern the joint and are considered as relatively innocent, we think that inadequate treatment may be experienced and therefore more attention should be paid.

Fixation with K-wires is the most commonly used method in the treatment of SH type 2 distal femoral physeal fractures [14]. In a study by Inal et al., they analyzed von Mises stress distributions in the growth cartilage in the models pinned in four different configurations in SH type 2 fractures. They said that the increase in stress values in the fracture line was an indication that the stability of the fixation was low. As a result of their analysis, they indicated that the cross-pinning model was the most stable model from a biomechanical point of view [10]. Although the pinning method is a frequently used method in treatment, it has important complications. Although there are studies that found that the K-wires, crossing the growth cartilage, do not form physeal bars, many studies have stated that it increases the formation of the physeal bar, which causes elongation problems and deformities [15-17]. In addition, pin tract infection due to percutaneous K-wires can be seen frequently, while septic arthritis has also been reported [14].

Two parallel screw methods, placed from the metaphyseal part, are a method that protects the growth cartilage. Garet et al. stated that if the metaphysical part is large enough in SH type 2 fractures, the parallel screw technique that protects the physis and is placed from the metaphysis is an ideal treatment and provides stable fixation [14,15,18]. Ilharreborde et al. stated that fixation with screws inserted from the metaphysis in SH type 2 fractures may not provide sufficient stability and fixation should be protected with plaster [11].

In our study, we tried to determine which method is the most stable by comparing the methods of cross pinning and fixation with two parallel screws placed from the metaphyseal part biomechanically. As a result of our analysis, we found that in the cross-pinned model, in axial loading, varus bending, valgus bending, anterior bending, posterior bending, and torsional loads, the stresses of growth cartilage was significantly lower. Based on these data, we can say that the cross pinning method provides more stable fixation with two parallel screws, placed from the metaphyseal part, and reduces the stress more in the growth cartilage.

The first displacement amount and displacement direction of the fracture is an indicator in terms of instability. Arkader et al. found a correlation between the type of fracture and the amount of displacement and complications. They did not find a significant relationship between displacement direction and complications [13]. We think that the direction of displacement of a fracture is guiding in the direction in which it can be displaced in the follow-up. In our study, we found that in valgus bending performed, models fixation with cross K.-wire reduces the overloading on the growth cartilage by 6 times compared with fixation with a screw. Similarly, we found that the stress value in the growth cartilage decreased by approximately 4 times in the model we applied varus bending, which was fixed with cross K-wire. Based on these results, we think that preferring the cross pinning method is biomechanically safer, especially in fractures with high coronal plane displacement.

Our study is a computer-supported biomechanical study. Therefore, the inability to analyze data such as immobilization time and weight-bearing status, which may affect the prognosis of pediatric fractures, can be shown as our missing side. New clinical experimental studies are needed on this subject.

In conclusion, in Salter Harris type 2 distal femur fractures, the cross-pinning method was biomechanically superior and provided more stable fixation than the two parallel screw method placed from the metaphyseal part. It is safer to prefer the cross pinning method, especially for fractures displaced in the coronal plane. The parallel screw method may be preferred in fractures with large metaphyseal parts because it protects the growth cartilage, but it should be taken into consideration that it may not provide sufficient stability.

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Scientific Responsibility Statement
The authors declare that they are responsible for the article's scientific content including study design, data collection, analysis and interpretation, writing, some of the main line, or all of the preparation and scientific review of the contents and approval of the final version of the article.

Animal and human rights statement
All procedures performed in this study were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. No animal or human studies were carried out by the authors for this article.

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Conflict of interest
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